



United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA 22092



In Reply Refer To:
WGS-Mail Stop 519

4 2 1988

Mr. Thomas N. Pyke, Jr.
Assistant Administrator for Satellite
and Information Services
Federal Building 4, Room 2069
Washington, D.C. 20233

Dear Mr. ^{Tom}Pyke:

In response to the announcement in the April 1, 1988, Commerce Business Daily regarding "Study for Advanced Civil Earth Remote Sensing System," the U.S. Geological Survey submits the enclosed recommendations for the system requirements and configuration. These recommendations represent a consensus of scientists in the Geologic Division, Water Resources Division, and the National Mapping Division of the U.S. Geological Survey. They have also been submitted for review by the Department of the Interior Remote Sensing Task Force as a mechanism to obtain concurrence by the other bureaus in the Department.

The proposed parameters assure continuity with the highly successful multi-spectral sensing conducted by Landsat 1 through 5, and would provide the optimum ground resolution compatible with economical operation. The system would also produce a fundamental worldwide digital elevation data set that is needed to produce 20 m or better topographic contour data, and for spectral reflectance modelling for compositional determinations, geologic hazards studies, toxic waste monitoring, structural analyses, and several other applications.

We have not addressed any aspects of commercial financing or data marketing for such a system. However, the public sector, as represented by government agencies at various levels, has consistently been the principal buyer and user of Landsat and SPOT data, and we expect that this market share will be maintained in the future. We believe that the proposed system could provide extremely useful data at a price which would make it economically attractive to a wide variety of users. We anticipate that international government support would be enhanced if the system operators were part of, or at least backed by, a recognized governmental or international organization.

The basic parameters of the recommended satellite system have been verified by a technical study conducted by Itek and TRW. Furthermore, they have been endorsed by the 1984 Congress of the International Society for Photogrammetry and Remote Sensing, which represents the mapping interests of 73 member countries.

Scientists at the U.S. Geological Survey are prepared to present additional documentation and participate in requested briefings or technical discussions on this system.

Sincerely yours,

DAL

Dallas L. Peck
Director

April 1988

U.S Geological Survey
Recommendations
for
STUDY FOR ADVANCED CIVIL EARTH REMOTE SENSING SYSTEM

Landsats 1 through 5 have demonstrated the substantial utility of multispectral sensing for planimetric and thematic mapping and for monitoring changes taking place on the surface of the Earth. The French SPOT has demonstrated the advantages to be gained by increasing the ground resolution from 30 m/pixel (Landsat TM) to 20 m/pixel in multispectral bands and 10 m/pixel in panchromatic response. SPOT has also demonstrated the increased geometric integrity of linear arrays over the oscillating scanner employed in the TM. Furthermore, SPOT has shown the feasibility of extracting topographic elevation data from stereoscopic linear array data acquired by cross-track pointing of the sensor from separate orbital passes. However, it has also demonstrated that cross-track pointing is not the optimum mode for acquiring stereo data. The Japanese JERS-1, to be launched in a few years, will employ the preferred fore-and-aft pointing to acquire continuous stereo data, but at lower resolution than SPOT. Cross-track pointing does have, of course, the advantage of permitting more looks at areas of time-critical interest.

The President's revised space policy [reference 1] encourages new U.S. civil remote sensing satellite systems to be "competitive with, or superior to, foreign-operated civil or commercial systems," and economically viable without extensive government subsidy.

Thus, a minimum set of requirements for a new U.S. civil remote sensing satellite would include:

- o Multispectral linear array data in several spectral bands with established utility.
- o Effective ground resolution equal to or better than 10 m/pixel.
- o Fore-and-aft stereo data acquisition to produce digital elevation data with accuracy comparable to the ground resolution.
- o Continuous and systematic global coverage at data transmission rates not requiring extensive modification of existing receiving stations.
- o Economical system design and cost-effective operation.

There is a natural tendency for scientists to seek more and more refined data sets - particularly with respect to increased spatial resolution and additional spectral bands. However, these improvements can be obtained only at the expense of much more complicated and expensive spacecraft, sensors, and data handling systems, which will almost certainly violate the requirement for commercial viability. Furthermore, experimental sensors proposed for the Earth Observation System (EOS) on the polar-orbiting platforms of the Space Station will provide several hundred very narrow spectral bands throughout the useful portions of the electromagnetic spectrum. It is worthy of note that effective application of these EOS sensors will require a comprehensive digital elevation model.

The U.S. Geological Survey believes that the next generation of Landsat should not attempt to provide all the types of experimental data that scientists would like to see, but be restricted to a limited set of proven utility which can be made available from a relatively simple cost-effective operational system.

It is not the intent of this document to provide a detailed system design, but simply to present a set of key parameters from which the system can be engineered. These parameters are as follows:

1. Spectral bands

Three spectral bands are the minimum:

Blue-green (0.47 to 0.57 μm) - for water penetration and shallow sea monitoring at depths up to 30 m.

Red (0.57 to 0.69 μm) - for optimum recording of natural and cultural features.

Near-infrared (0.76 to 1.05 μm) - for vegetation response, delineation of water boundaries, and atmospheric haze penetration.

In addition, a shortwave infrared band (SWIR) (1.50 to 1.75 μm) would be particularly useful for geologic discrimination, leaf water content, and snow/ice/cloud delineation. However, detectors in this spectral range require cooling, leading to a more complicated and expensive spacecraft.

2. Ground resolution

System capability should be equal to or better than 10 m/pixel in the three primary spectral bands. This spatial resolution is compatible with the preparation of 1:50,000-scale multicolor image maps. For areas with dense planimetric detail the technique of systematic misregistration of the separate bands [reference 2] may permit higher resolution output to be obtained by ground processing of data. On-board pixel clustering should

permit reduction to 20 or 30 m/pixel for areas of low interest. Consideration should be given towards 5 m/pixel resolution in the red band, or possible use of a 5 m/pixel panchromatic band, provided a separate optical system is not required. The SWIR band would be adequate at 30 m/pixel.

3. Quantization

Original data should be quantized at 8 bits per pixel. On-board non-destructive data compression schemes should be utilized to reduce the transmission rate. Six-bit quantization of SWIR data, if included, should be adequate.

4. Sensor configuration

Three separate optical systems with cross-track sets of linear arrays are required - one pointing to the nadir and the others $\pm 23^\circ$ along the line of flight, as shown in Figure 1 [extracted from reference 3]. Optical system parameters will be dictated by ground resolution, detector size, swath width, and spacecraft altitude.

5. Swath width

A maximum swath width of 180 km should be provided at 10 m/pixel resolution for global monitoring. For stereo data acquisition, and particularly if a 5 m/pixel band is included, the swath should be adjustable down to a minimum of 62 km.

6. Orbit

Sun-synchronous near-circular polar orbits are available at altitudes between 590 and 920 km. The lower orbits provide equivalent ground resolution with a smaller optical system, but require a larger cross-track field of view for the same swath width, with a consequent degradation of image quality. With 180 km swath width, the 918 km orbit provides adjacent swaths on consecutive days, which is more advantageous to acquire large contiguous areas of coverage. Furthermore, the higher orbits increase the area of data acquisition by ground reception stations.

An early morning, 0830 to 0930, descending node provides adequate illumination but low enough solar elevation to provide good scene contrast and optimum conditions for stereo image correlation.

Launch time and date should take into consideration the orbital parameters of existing imaging satellites so that more frequent Earth observation opportunities are available through cooperative scheduling.

7. Spacecraft position

A Global Positioning System receiver (or current equivalent) should be provided to give spacecraft position during all operating sequences. The required accuracy of 3 to 5 m in all three coordinates should be easily obtained.

8. Spacecraft attitude

Nadir pointing during stereo mapping sequences should be provided to about 0.1 degree. However, knowledge of actual pointing direction should be provided to a few seconds of arc when the satellite is in the mapping mode. Electro-optical focal plane array stellar sensors with real-time computation are considered the best way to achieve this attitude information [reference 4].

To achieve precise geometric mapping at accepted standards for 1:50,000 scale with minimum ground control, spacecraft attitude rates should be held to within 10^{-6} degrees per second. This implies a spacecraft with no moving parts during data acquisition.

Cross-track pointing should be avoided during stereo mapping sequences because it greatly complicates data processing and scene indexing. However, once stereo mapping coverage has been acquired, cross-track pointing may be used to increase frequency of observation for time critical sites.

By continuous programming of spacecraft (or sensor) attitude, it is possible to make forward- and aft-looking detectors track the same ground path. This technique permits acquisition of stereo data in the epipolar condition and will greatly reduce ground processing [reference 5].

9. On-board data storage

In order to provide systematic global data acquisition without a great increase in the number of ground stations, on-board data storage will be required. Sufficient storage should be provided for several hundred km of ground track at 180 km swath and 10 m/pixel resolution with 3 multi-spectral arrays and 1 stereo array operating. If near real-time non-destructive data compression can be accomplished, storage requirements can be reduced.

10. On-board control computer

An on-board computer is needed for selecting which arrays will be operating, controlling pixel resolution, swath width, off-nadir pointing, attitude computation, etc.

11. Data transmission

X-band data transmission has been internationally accepted for remote sensing data. If at all possible, data rates should be constrained to those which can be received by most existing ground stations without major modification. Optimum on-board nondestructive data compaction should be employed to maintain these data rates.

12. Ground processing

All of the ground processing techniques currently applied for resampling, image enhancement, and geocoding are applicable to the proposed system. What is new is the continuous automated processing of digital stereo data. Matching image data from separate sets of arrays during ground processing permits stereoscopic determination of the height of all ground points with accuracy comparable to ground resolution. For topographic mapping, contour lines at about 20 m interval can be derived from these digital data. If the original data are acquired in the epipolar mode (as described in Section 8, paragraph 4) data processing to produce digital terrain information and orthographic image mapping will be reduced by about an order of magnitude. Production of a geo-coded digital elevation data set should be a function of the system operator rather than the individual users.

The parameters recommended above will produce a system that has capabilities for mapping and monitoring the Earth which are not approached by any other existing or proposed satellite. The system concept requires an uncomplicated spacecraft and an economical data handling system.

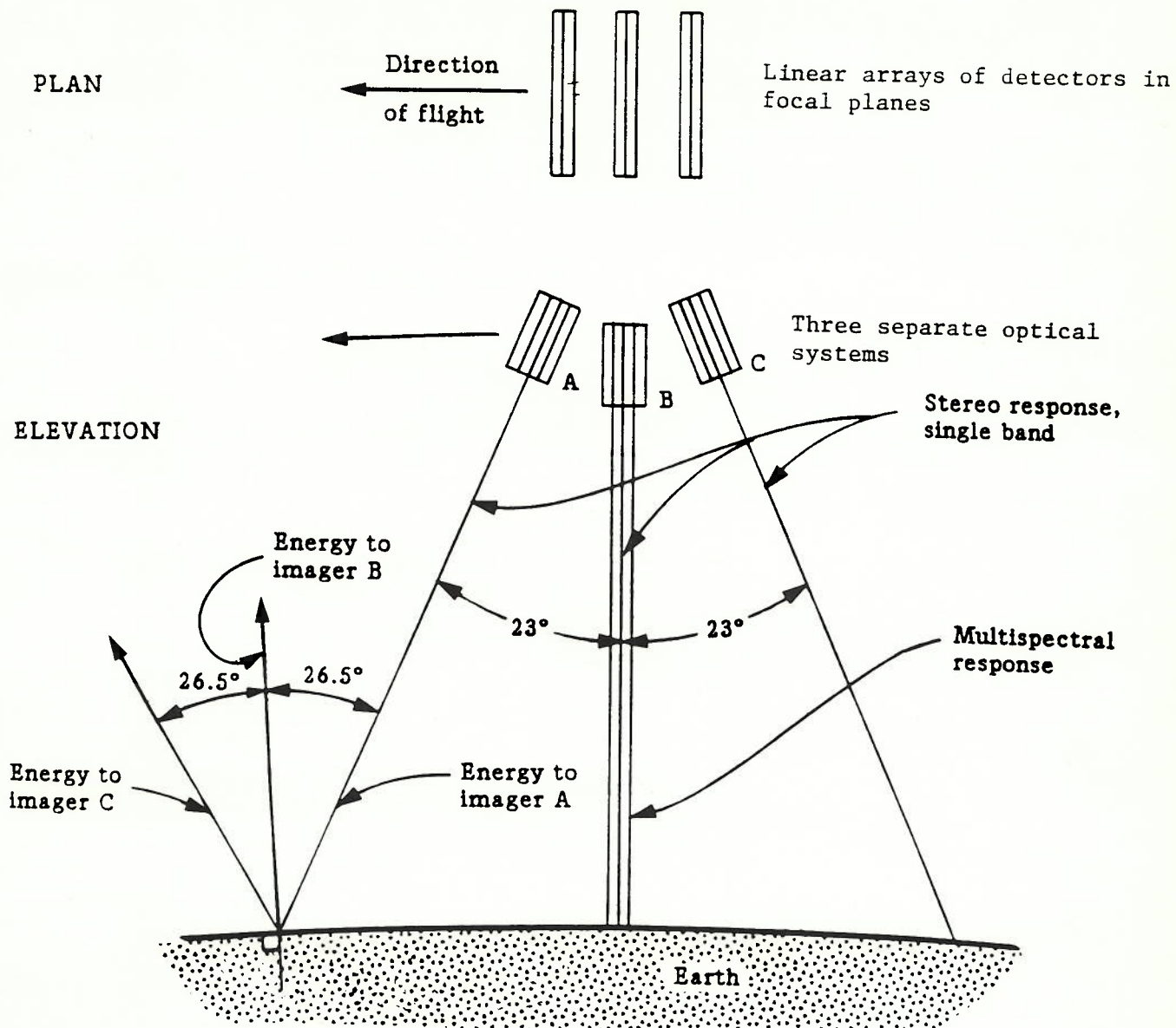
The basic parameters of the recommended system have been verified by a technical study conducted by Itek and TRW [reference 6]. Further, they have been endorsed by the 1984 Congress of the International Society for Photogrammetry and Remote Sensing [reference 7], which represents the mapping interests of 73 member countries.

Scientists of the USGS are prepared to provide copies of the references and to participate in any requested briefings regarding the proposed system.

REFERENCES

1. White House Press Release of February 11, 1988, describing new National Space Policy as approved by President Reagan on January 5, 1988.
2. Department of the Interior Patent Application for A Solid State Apparatus for Imaging with Improved Resolution (SUR-3313), April 2, 1985. Patent granted March 1988.
3. Colvocoresses, A. P., 1982. - An Automated Mapping Satellite System (MAPSAT). Photogrammetric Engineering and Remote Sensing, Vol. 48, No. 10, October 1982, pp. 1585-1591.
4. Strikwerda, Thomas E., and John L. Junkins, 1981. - Star Pattern Recognition and Spacecraft Attitude Determination. Virginia Polytechnic Institute and State University Report ETL-0260 for Engineer Topographic Laboratories, May 1981.

5. Snyder, John P., 1982. - Geometry of a Mapping Satellite. Photogrammetric Engineering and Remote Sensing, Vol. 48, No. 10, October 1982, pp. 1593-1602.
6. Itek Optical Systems, 1981. - Conceptual Design of an Automated Mapping Satellite System. Contract report for U.S. Geological Survey, No. 14-08-0001-18656, February 3, 1981.
7. ISPRS, 1984. - Report of the Committee for Acquisition and Processing of Space Data for Mapping Purposes of Working Group IV/3 of the International Society for Photogrammetry and Remote Sensing, June 1984.



Imagers A, B, and C are rigidly connected. Imager B senses the same strip 60 seconds after A; imager C, 120 seconds after A. Any combination of A, B, and C produces stereo. Imagers A and C are about 10% longer focal length to provide resolution compatible with imager B.

Figure 1. Proposed Sensor Configuration to Acquire Multispectral Stereo Image Data

ANSWERS TO QUESTIONS FROM NOAA
ON OTHER DATA SOURCES THAT WOULD BE USED BY
THE DEPARTMENT OF THE INTERIOR
IF LANDSAT 4/5 OPERATIONS ARE DISCONTINUED

1. If there is no Landsat, what sources of data will we use?

We will consider using a variety of sources if current (new) Landsat data are not available.

A. Existing Landsat Data

--DOI will continue to use existing Landsat data where available for applications not requiring current data, if an ordering/processing mechanism exists to provide data to users. For most geologic studies, existing Landsat data will still be an adequate data source.

B. Other Satellite Data

1. SPOT data--Interior will have to rely more on data from the French SPOT satellite which has slightly higher spatial resolution, but fewer spectral bands and is significantly more expensive for coverage of large areas.
2. AVHRR data--are only being used for a few regional monitoring applications where 1-km data are appropriate. We cannot substitute AVHRR for DOI uses that currently use TM or SPOT because of needed spatial and spectral resolution.
3. Sovuzkarta space photography--We have been examining a few test scenes; at this point it is unlikely that it will be used for Interior resource monitoring or research projects.

C. Aerial Photographs

1. National Aerial Photography Program or other high-altitude photographs--could be used for some resource mapping tasks but photographs may not be current (5-6 year repeat cycle). The photographs are not in digital form and we would need to perform visual photo interpretation and digitize the results to use in a geographic information system; most bureaus don't have staff to do this.
2. Acquire new special-purpose aerial photos--We may do this for specific projects where we need current data.
- D. Abandon the Use of Satellite Data--We would choose this option for applications requiring current year data (and SPOT or other data is not suitable) or if we need spectral information found only in Landsat TM bands.

- E. Return to Traditional Methods-Field Inventory/Mapping--This option would be considered where resource information is required and other sources are not appropriate.

2. **How much more would it cost (to use other sources).**

- A. Existing Landsat Data--no increased cost, assuming same prices.
- B. Other Options: We cannot estimate since uses are made by many bureaus who would have to decide on an application-by-application basis what source(s) to use or if to continue.